ESTIMATION AND VALIDATION OF WIND SPEED BY USING SPATIAL INTERPOLATION

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ABSTRACT

The increasing of wind hazard damages in Malaysia shows that wind speed has played an important role in weather forecast. Interpolation method is vital when estimating wind speed especially for a location which do not has a weather forecast station. In this study, three methods of spatial interpolation which are Inverse Distance Weighting (IDW), Kriging and Spline were compared to determine their suitability for estimating wind speed. All the methods are evaluated by using standard error regression and correlation coefficient analysis. Based on the results obtained, it was shown that Kriging is more suitable when estimating wind speed for a study point within an enclosed area while IDW and Spline are more suitable for study point between two locations. Therefore, the suitability of different spatial interpolation method is varies for different arrangements of location. Future studies with more data collected, denser sample points and different cases can be carried out to obtain a more accurate result.

ABSTRAK

Kerosakan yang disebabkan oleh bencana angin yang semakin meningkat di Malaysia menunjukkan kelajuan angin memainkan peranan yang penting dalam rekabentuk terhadap bangunan. Kaedah interpolasi adalah sangat penting apabila membuat anggaran kelajuan angin terutama bagi lokasi yang tidak mempunyai stesen ramalan cuaca. Dalam kajian ini, tiga kaedah interpolasi spatial iaitu 'Inverse Distance Weighting' (IDW), 'Kriging' dan 'Spline' telah dibanding untuk menentukan kesesuaian kaedah-kaedah tersebut dalam menganggarkan kelajuan angin. Semua kaedah dinilai dengan menggunakan regresi ralat piawai dan analisis koefisien korelasi. Berdasarkan keputusan yang diperolehi, ia menunjukkan bahawa kaedah 'Kriging' adalah lebih sesuai bagi menganggarkan kelajuan angin dalam kawasan yang tertutup manakala kaedah IDW dan 'Spline' lebih sesuai untuk titik kajian antara dua lokasi. Oleh itu, kesesuaian kaedah interpolasi spatial adalah berbeza bagi susunan lokasi yang berbeza. Di masa hadapan adalah dicadangkan supaya kajian mengguna pakai lebih banyak data.

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LIST OF SYMBOLS

Km/hr	Kilometers per hour
S	Standard error of regression
r	Correlation coefficient
$\hat{Z}(s_o)$	Predicted and observed value at location s_o
$Z(s_i)$	Predicted and observed value at location s_i,
N	Number of measured sample points used in the prediction
$w(d)$	Weighting function
d_i	Distance from s_o to s_i
$N(h)$	Number of pairs of measurement points with distance h apart
Σ	Sum
°E	Longitude
°N	Latitude

LIST OF ABBREVIATIONS

UMP	Univeristi Malaysia Pahang
GIS	Geographical Information System
IDW	Inverse Distance Weighting
MMD	Malaysian Meteorological Department
ESRI	Environmental System Research Institute

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Wind is flowing of air in our atmosphere caused by difference in air pressure where the greater the differences in air pressure, the faster the air flows. Wind has two characteristics namely wind speed and wind direction. Wind speed can be measured by using anemometer and wind speed data can be collected at meteorological station. There are various types of wind such as breeze, crosswind, gust, monsoon, tornado, typhoon, whirlwind and windstorm. A gentle wind is nice but a strong wind might cause damages.

Wind hazard damages in Malaysia has been increasing every year and various wind hazard damages has been reported by Malaysian Meteorological Department (MMD). On 16th July 2013, a strong wind hit West Coast of Sabah and Labuan resulted in fallen trees in various areas, causing damage to houses and vehicles, as well as traffic congestion. Meanwhile, power disruptions caused by trees and branches that had fallen on electric cables were also reported. The highest wind speed of 74 km/hr was reported by Kota Kinabalu Meteorological Station. (MMD Weather Report, 2013)

Besides, on 29th September 2014 and 21st October 2014, strong wind and thunderstorm had occurred in Bukit Jelutong, Shah Alam and Pandamaran, Klang respectively. The roof tiles of houses were blown off and cars were damaged by fallen trees. Other than that, a tornado had occured in Kampung Sungai Nonang, Kota Sarang Semut, Alor Setar on 12th November 2014. According to the report, this small scale of tornado resulted in many fallen trees and roof damage of around 20 houses and 4 shop-houses. (MMD Weather Report, 2014)

Figure 1.1: Damages caused by the tornado in Kampung Sungai Nonang

Source: Harian Metro, 12th November 2014

This shows that wind has played an important role in weather forecast. In order to prevent more wind hazard damages occur, it is important to forecast wind speed for a location. Since not all the places around Malaysia has meteorological station, obtaining wind speed at a location without meteorological station requires some form of spatial interpolation. Spatial interpolation by using Geographical Information System (GIS) can be used to estimate wind speed for a location. A variety of interpolation methods are available but accuracy vary among methods depending on the spatial attributes of the data.

1.2 PROBLEM STATEMENT

Before constructing any building or structure, it is important to determine the wind direction and wind speed for that location. Engineer can design the building or structure with higher resistance to the wind speed. This can prevent or reduce wind hazard damages that might occur for that location. However, not every place has meteorological station, so estimation of wind speed by using interpolation is vital especially for location without meteorological station.

There are various spatial interpolation methods, such as Inverse Distance Weighting (IDW), Kriging, Natural Neighbour, Spline, Topo to Raster, and Trend. Different methods have different conditions and produce different results. Furthermore, wind speed data of known locations are required to estimate wind speed at unmeasured locations. The arrangement of known locations which have meteorological station are not consistent and might give different results when carrying out different interpolation methods.

1.3 OBJECTIVE

The suitability to estimate wind speed for a location by using different spatial interpolation methods with different arrangements of known location need to be determined. Therefore, there are two objectives in this study which are:

i. To interpolate wind speed by using three different methods of interpolation namely IDW, Kriging and Spline.
ii. To identify the best fit method to interpolate for different arrangements of location around Peninsular Malaysia, Singapore and Indonesia.

1.4 SCOPE OF STUDY

The scope of this study is to determine the ways to succeed the objectives. The scopes of this study are:

i. 10 locations around Peninsular Malaysia, Singapore and Indonesia.
ii. Locations are divided into either study point within an enclosed area (Figure 1.2) or study point between two locations (Figure 1.3).
iii. Three interpolation methods compared are IDW, Kriging, and Spline.

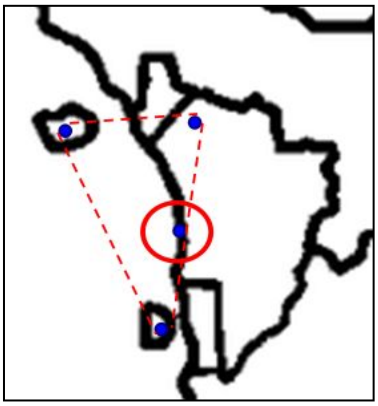

Figure 1.2: Study point within an enclosed area

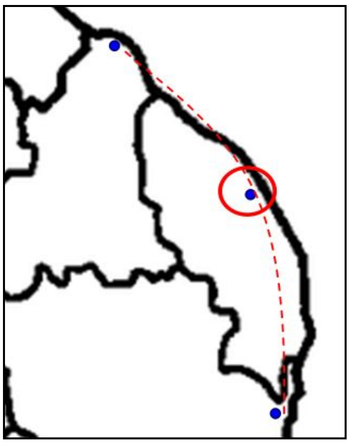

Figure 1.3: Study point between two locations

1.5 AREA OF STUDY

The area of study is limited to certain states in Peninsular Malaysia, Singapore and Indonesia. The 10 locations chosen are the meteorological station of the airport in the respective states (Figure 1.4).

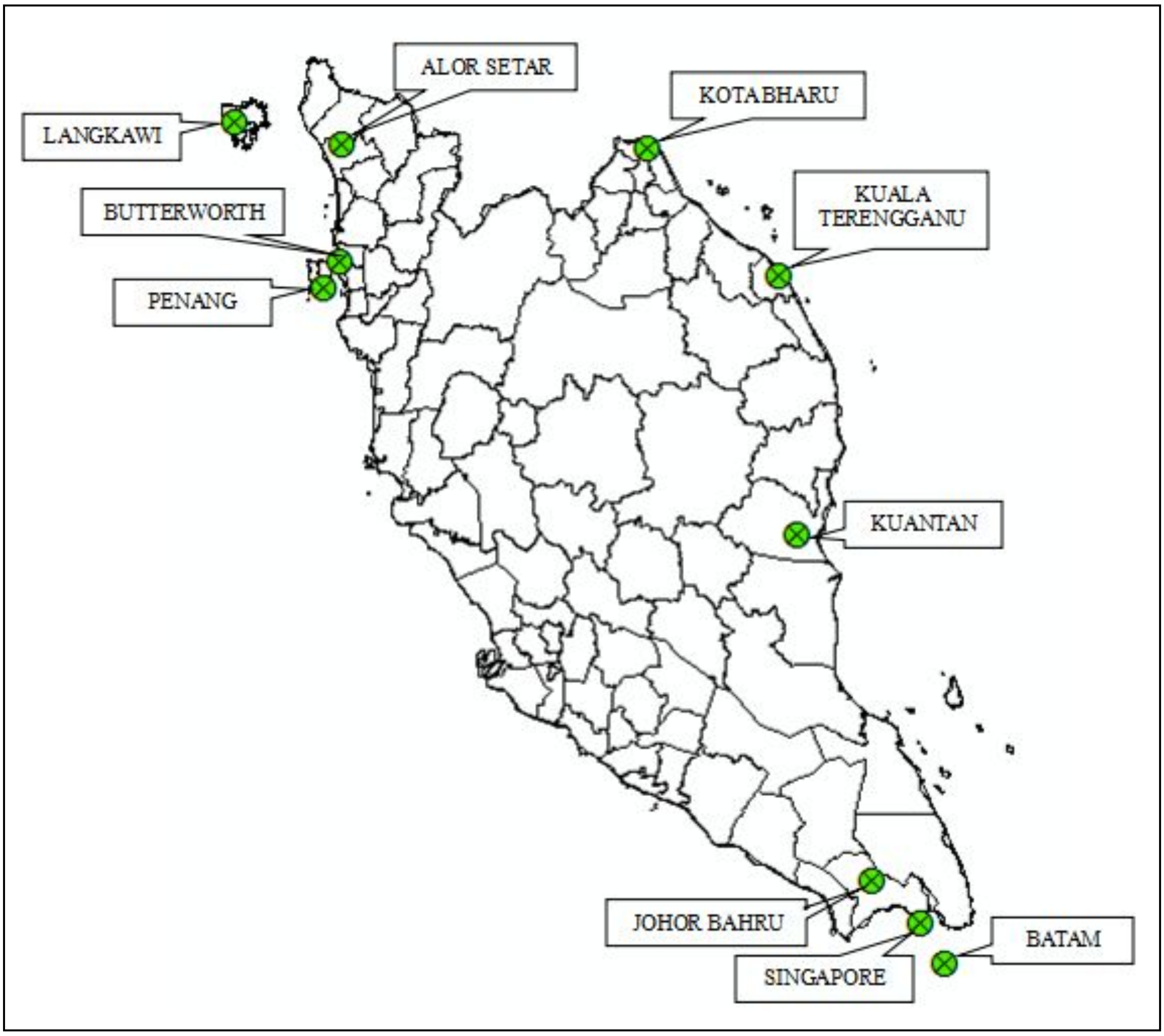

Figure 1.4: 10 locations chosen for this research

1.6 RESEARCH SIGNIFICANT

By carrying out this study, the suitability to estimate wind speed for a location with different arrangements of known location by using different interpolation methods can be determined. This can be a simple guideline when using spatial interpolation to estimate wind speed for a location. For example, if the study point is within an enclosed area of known locations, a specified interpolation method is more suitable to be used. On the other hand, if the study point is between two known locations, another specified interpolation method will be more suitable.

1.7 THESIS LAYOUT

There are five chapters in this thesis:

i. CHAPTER 1 : Introduction
This chapter shows the background, overview of problem statement, objective, scope of study, study area and research significant.

ii. CHAPTER 2 : Literature Review
This chapter shows a review of past research related to the objective of study.

iii. CHAPTER 3 : Methodology
This chapter shows the research method used in this study

iv. CHAPTER 4 : Result and Discussion
This chapter shows the results obtained and discussion based on the results.

v. CHAPTER 5 : Conclusion and Recommendation
This chapter shows the conclusion for this study and provides some future recommendation to improve the results obtained.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provide a review of past research related to estimation of wind speed by using interpolation in. A review of other relevant research studies about spatial interpolation is also provided. This review will focus on wind and spatial interpolation.

2.2 WIND

Wind is flowing of air in our atmosphere caused by uneven heating of Earth by the sun. Wind cannot be seen or caught but we can feel its force, thus it is usually described by its direction and speed. It is a very good equalizer for the atmosphere, transporting heat, moisture, pollutants, and dust. The differences in atmospheric pressure produce wind. Generally, wind flow from high pressure areas to low pressure areas

2.2.1 Types of Wind

As wind travels at different speeds, altitudes and over water or land, thus it can cause different types of patterns. There are various types of wind such as breeze, crosswind, gust, monsoon, tornado, typhoon, whirlwind and windstorm. A gentle wind is nice but a strong wind might cause damages.

2.2.2 Wind Speed

Wind speed is the measure of the air motion with respect to the surface of earth covering a unit distance over a unit time. In Malaysia, wind speed is usually measured in kilometer per hour. An anemometer is a device used to measure wind speed.

The amount of force that wind is generating is measured according to the Beaufort scale. The scale is named for Sir Francis Beaufort, who established the system for describing wind force in 1805 for the British Royal Navy. The Beaufort scale has 17 levels of wind force (National Geographic Education).

2.2.3 Wind Hazard Damages

Wind hazard damages are natural disaster caused by strong wind. Wind hazard include hurricanes, tornadoes, typhoon and other windstorms are threats to many places around the world causing damages such as high levels of injuries, deaths, property damages, and business interruption. In Malaysia, wind hazards such as strong wind, gale and small scale tornado can be found. Gale often happens around urban area.

From the weather reports for year 2013 and 2014 by MMD, most of the wind hazard damages caused by gale and thunderstorm were from Klang Valley. On 29th September 2014, more than 100 houses experienced roof damages and cars are damaged by fallen trees in Shah Alam. On 12th October 2014, the thunderstorm occurred in Kuala Lumpur causes the death of two policemen after the trailers used to store case objects are struck by fallen trees. On 21st October 2014, the strong wind in Pandamaran, Klang causing damages to around 30 houses.

Furthermore, small scale of tornado often spotted in Alor Setar, Kedah. On 14th October 2014 and 12th November 2014, many houses were damaged and fallen trees were everywhere due to the tornado. From the weather report, it stated that this tornado was caused by unstable atmosphere with high air humidity.

Figure 2.1: Tornado in Alor Setar

Source: Berita Harian Online, 14th October 2014

Figure 2.2: Damages caused by tornado in Alor Setar

Source: Malaysiakini 12th November 2014

2.3 SPATIAL INTERPOLATION

Spatial interpolation is the prediction of variables at unmeasured locations based on samples at known locations. Spatial interpolation method by using GIS can be used when estimating wind speed for a location. There are various spatial interpolation methods such as IDW, Kriging. Natural Neighbor, Spline, Topo to Raster, and Trend.

Weather data are generally recorded at point locations, so some form of spatial interpolation is required to estimate data values at other locations. A variety of deterministic and geo-statistical interpolation methods are available to estimate unmeasured locations but, depending on the spatial attributes of the data, accuracy vary widely among methods. The final use of any interpolated variable surface must also be taken into account because different methods result in different surfaces (Willmott, 1984)

Spatial interpolation is more worthwhile if a sufficient density of weather stations is available across the study area. The density of the network required depends upon the variable to be estimated. Wind speed, for example, is more variable over shorter distances than temperature or relative humidity, and hence would be expected to require a more dense network of monitoring sites to achieve accurate and precise interpolated surfaces (Luo et al.,2008).

Spatial continuous data play an important role in planning, risk assessment, and decision-making in environmental management. However, they are usually not always readily available and often expensive and difficult to obtain. Environmental data collected on field surveys are typically from point sources. Environmental managers often require spatial continuous data over a region of interest to make effective decisions, and scientists need accurate spatial continuous data across a region to make justified interpretations (Chinta, 2014).

W. Luo et al. (2008) stated that there is a need to estimate the risk posed by the spreading of existing and invading non-indigenous pathogens or insects across the landscape. Studies on the risks posed by these pathogen and pests need to estimate how frequently wind speeds above various thresholds could be expected to push them between hosts. Rather than use the point value from the nearest recording station, which may be many kilometers distant (Luo et al., 2008).

There are many researches on comparison of interpolation methods for temperature and precipitation, (Phillips et al., 1992; Collins and Bolstad, 1996; Goovaerts, 2000; Price et al., 2000; Jarvis and Stuart, 2001; Vicente-Serrano et al., 2003; Chai et al, 2011) but few research effort have been directed towards comparing the effectiveness of different spatial interpolation methods in estimating wind speed.

When compared with other interpolation methods evaluated, cokriging was most likely to produce the best estimation of a continuous surface for wind speed and that result had temporal consistency (Luo et al., 2008). On the other hand, Sandeep Chinta (2014) stated that global polynomial interpolation was most likely to produce the suitable estimation of a continuous surface for wind speed (Chinta, 2014).

2.3.1 Inverse Distance Weighting (IDW)

The IDW function should be used when the set of point is dense enough to capture the extent of local surface variation needed for analysis. IDW determines cell values using a linear-weighted combination set of sample points. The weight assigned is a function of the distance of an input point from the output cell location. The greater the distance, the less influence the cell has on the output value (Colin Childs, 2004).

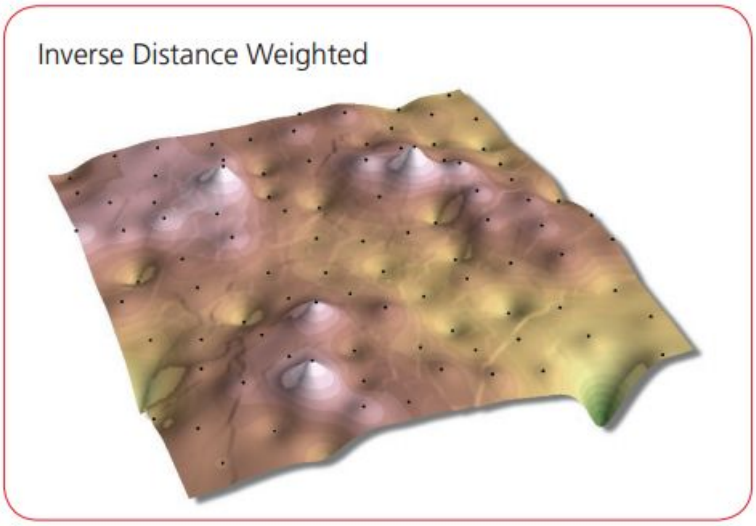

Figure 2.3: Inverse Distance Weighting

Source: ESRI Education Services (2004)

IDW interpolation combines the idea of proximity espoused by Thiessen Polygons (Thiessen, 1911) with the gradual change of a trend surface. Those measured values closest to the prediction location will have more influence on the predicted value than those further away. This distance-decay approach has been applied widely to interpolate climatic data (Legates and Willmott, 1990; Stallings et al., 1992). IDW assumes that each measured point has a local influence that diminishes with distance. The usual expression is expressed as in Eq. (2.1)

$$\hat{Z}(s_o) = \left[\sum_{i=1}^{N} w(d_i)Z(s_i)\right] / \left[\sum_{i=1}^{N} w(d_i)\right] \tag{2.1}$$

where $\hat{Z}(s_o)$, $Z(s_i)$ represent the predicted and observed value at location s_o, s_i,

N is the number of measured sample points used in the prediction,

$w(d)$ is the weighting function,and

d_i is the distance from s_o to s_i

Based on the structure of IDW expression, the choice of weighting function can significantly affect the interpolation results. The comparative merits of various wieghting functions are discussed in detail by Lancaster and Salkaukas (1986). The IDW parameters specified in ArcGIS are the power option, search shape, search radius and number of points. A circle with radius 100 km for each shape with minimum and maximum numbers of points of 10 and 15 were specified for IDW. The power was optimized automatically by ArcGIS.

2.3.2 Kriging

A powerful statistical interpolation method used for diverse applications such as health sciences, geochemistry, and pollution modeling. Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. It fits a function to a specified number of points or all points within a specified radius to determine the output value for each location. Kriging is most appropriate when a spatially correlated distance or directional bias in the data is known and is often used for applications in soil science and geology (Colin Childs, 2004).

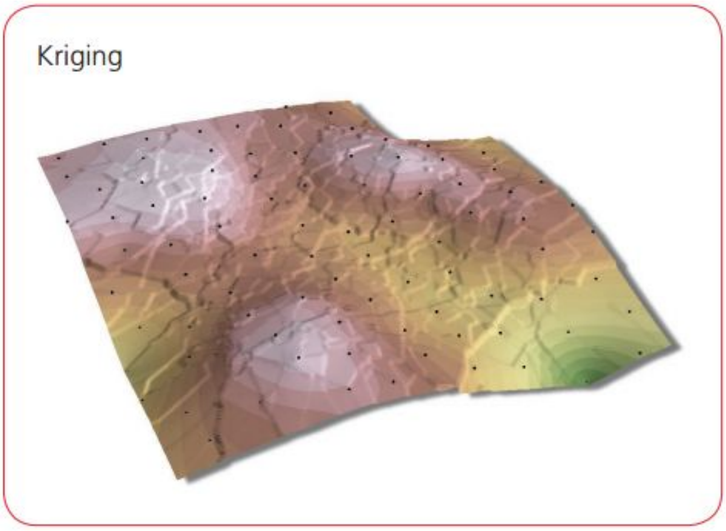

Figure 2.4: Kriging

Source: ESRI Education Services (2004)

Kriging (Krige, 1996) is a stochastic technique similar to IDW, in that it uses a linear combination of weights at known points to estimate the value at an unknown point. In contrast with deterministic methods, Kriging provides a solution to the problem of estimation of the surface by taking account of the spatial correlation. The spatial correlation between the measurement points can be quantified by means of the semi-variance function as in Eq. (2.2)

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(s_i) - Z(s_i + h) \right]^2 \qquad (2.2)$$

where *N(h)* is the umber of pairs of measurement points with distance *h* apart

Varieties of Kriging have been developed such as ordinary, universal, simple, and indicator, but only the first one is used in this study. Ordinary Kriging which assumes the mean is unknown, focuses on the spatial component and uses only the samples in the local neighborhood for the estimate. Universal Kriging is similar to that of ordinary Kriging, but assumes the presence of a trend in average values across the study area.

2.3.3 Spline

Spline estimates values using a mathematical function that minimizes overall surface curvature. This results in a smooth surface that passes exactly through the input points. Consequently, it is like bending a sheet of rubber so that it passes through the points while minimizing the total curvature of the surface. It can predict ridges and valleys in the data and is the best method for representing the smoothly varying surfaces of phenomena such as temperature (Colin Childs, 2004).

There are two variations of spline - regularized and tension. A regularized spline incorporates the first derivative - slope; second derivative - rate of change in slope; and third derivative - rate of change in the second derivative; into its minimization calculations. Although a tension spline uses only first and second derivatives, it includes more points in the spline calculations, which usually creates smoother surfaces but increases computation time (Colin Childs, 2004).

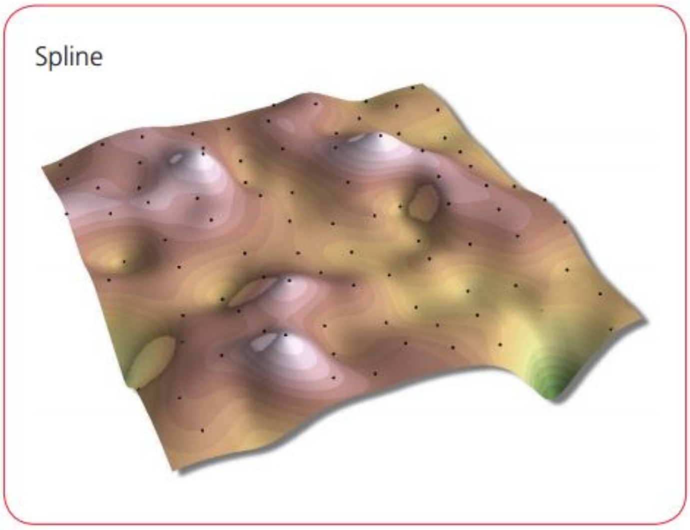

Figure 2.5: Spline

Source: ESRI Education Services (2004)

Spline is a commonly used deterministic interpolation method to represent two-dimensional curves on three-dimension surfaces. The Spline method produces good results for gently varying surfaces such as rainfall. Spline is not suitable when there are large changes in the surface values within a short horizontal distance (Yang et al., 2004).